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Phased Array Technology and Allerton

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Abstract: For the past fifty years the Antenna Applications Symposium at Allerton has provided a podium for engineers to discuss all aspects of antenna engineering . This paper addresses the subject of phased array development, and catalogs some of the papers presented at Allerton that have contributed to this development.

The Antenna Applications Symposium at Allerton has played a significant role in phased array development. From the time of its beginnings as the Air Force Antenna Symposium, Allerton has always offered two venues for communication, one is from the podium, and a second one takes place throughout the grounds and in the hallways and the dining area. To some this second venue may be the more valuable, but it has gone unrecorded. There is a fairly complete record of the presented papers and I have tried to highlight some of those that seem more relevant to phased array developments. This paper looks at the role played by the symposium in fostering those developments in array technology.

Table 1 gives a chronology of some representative array systems or major test-beds, along with component developments that support these systems. The various items of technology highlighted are array elements, control devices and array architectures. These major topics and subtopics are referenced against specific Allerton paper references in the Appendix, which lists the principle author and a few words to describe the subject.

There are some interesting trends revealed in the system applications and the items of technology. Throughout the 60's and 70's all array system applications used dipole and waveguide elements. Ferrite phase shifters controlled radars at S-band and above. Included are AWACS and AEGIS at S-band and the Patriot ground radar at C-band, the TPN-25 PAR antenna and GPN-22 at x-band.

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Array Elements

During the 60's and 70's most of the basic new array elements now in use were

discussed, and sometimes introduced at Allerton. In 1972 when Robert Munson introduced the microstrip patch antenna, it was two years before the AP-S paper by Munson was published. After that there have been numerous patch and printed circuit varieties, all tending toward wider band, better polarization and simpler excitation.
The first papers on notch and Vivaldi elements weren't presented at Allerton, but in 1977 George Monsor discussed new notch elements with 6:1 bandwidth. Since that time a number of papers, including several by our Chairman Dan Schaubert, attest to the durability of that research area and to the desirability of such wideband elements.

Array Control

There were very few ferrite or diode papers or T/R module papers presented during the early years at Allerton. There was an early paper by Adcock '54 that described a phase shifter using mechanically rotating crossed dipoles for UHF arrays. In '55 Von Aulock discussed geometries for ferrite phase shifter application. In '83 Hancic et.al. presented some very compact, lightweight diode phase shifters that represented the state of the art before MMIC.

In 1972 Collins and Hayes presented TI work on the RASSR modules, and later Harold Weber of AFRL presented a review of both MERA and RASSR modules. T/R module control of arrays grew from these first MERA and RASSR x-band test-bed demonstrations, and from the module developments from S-band to C-band that were summarized in 1980 by H. Chilton of Rome Laboratory. These included the first solid-state T/R module based system, the TPS-59, which consisted of slot arrays scanned in one plane. PAVE PAWS was the first all solid state phase-phase scanned radar.

Later, the MMIC program led to a number of integrated circuit MMIC arrays, now with multi-element modules or "trays" of MMIC modules directly integrated into the array aperture. These sorts of papers have continued to be presented at Allerton, and reflect a major change in array design, and a major change in this symposium, which now regularly accepts papers on all kinds of array control technologies. (See. For example '80 Chilton, '83 Edward, '85 Smetana et al, '87 Pepe et.al., '94 Edward, '95 Raquet).

New means of Control

Certainly ferrite phase shifters and diode phase controls, whether in active modules or passive phase shifter circuits, have been the mainstay for array control

in developed systems, but in the 1990's there were a large number of papers that addressed alternative means of beam control. These technologies are digital beam-forming, optical beam-forming and signal distribution, and MEMS phase control. The papers on digital beam-forming have not dealt with devices (A/D converters, filters etc.), but with array architecture using digital beam-forming ('92,'93 papers by Brandow and Humbert), error analysis of DBF systems, the use of neural networks for control in the presence of failures ("92 O'Donnell, '93 Simmers, '94-'96 Southall) and failure correction ('94 Mailloux).

Optical control of arrays became a topic at Allerton during the '90's, with major presentations in '92 by Herczfeld and Newberg, special sessions in'96 and '98 organized by Mike VanBlaricum, and the growth of the Navy program in photonic control (see '95 Parent, '97 Frankel et.al, and Bobowicz et.al.). A special session in '99 featured a number of papers on MEMS phase shifters and time delay devices.

Allerton has not seen many papers on adaptive array control. Probably because these went to the Air Force sponsored Adaptive Array Symposium, but there were several important early presentations b y Compton ('69) and others. Other papers ('81 Fenn and '81 Steyskal) have dealt with the array aspects of adaptive control (degrees of freedom consumed), and the formation of wide-band nulls ('95 Mailloux). In this regard one interesting presentation was the paper in '83 by Schmitt, who presented the MUSIC algorithm well in advance of the AP-S March '86 publication that described this important work on direction-finding. A special session in '00 convened by Wicks presented much current work on STAP (space-time adaptive processing).

Array Architectures

This category is interpreted broadly here, and at one extreme it includes waveguide slot arrays for low sidelobes (Evans/Hoofer '80), an early presentation of Joint Stars array technology by Harold Schnitkin in '89, and monopole synthesis with edge slot arrays by Kinsey in '95. Space fed lens ('97 Tripp and '97 Diaz) and reflectarrays ('62 Malech, '78 Montgomery, '93 Litva et.al). The '62 Malech paper is one of the earliest reflectarray references cited.

Several UHF rotodome antenna geometries ('56 Kinega, '58 Lockheed staff) were presented at Allerton, and though these were not conformal arrays, the subject of platform interaction was considered.

Members of the Hughes Corporation staff treated the topic of antennas conformal

to structures like cones and cylinders in 1952, at one of the very first Allerton symposia. Since then, various conformal array structures have been discussed at Allerton presentations, including the Navy work (Gladman et.al.'71) and a group of air Force programs ('73 Balzano, '89 Herper et al., '89 Hanfling) and including the low sidelobe circular array work of Herper and Stangel in 1980.

Multiple beam antennas have been a popular topic at Allerton throughout the years; beginning with the octave band MBA presented Mehron in 1963. A number of these are listed in the Appendix. In 1997 Jack Schuss presented an important paper on the IRIDIUM antenna, which, upon revision, was submitted to the AP-S transactions, where it won the "2000 Wheeler Applications Prize Paper Award".

Subarray technology and limited field of view antennas are related technologies, and have been a special subject of Air Force research since the late 1970's. Of particular interest are the papers of Southall and McGrath ('80 and "85) which later led to their receipt of the AP-S "1987 Wheeler Applications Prize Paper Award", the 1983 paper by Sinnott that described the Australian Ginda Lee OTH Radar, and new work by Kinsey in '98 describing subarray choices for limited field of view.

In 1972 Blakely, Burke end Cohn presented one of the first papers on meanderline circular polarizers.

Although primarily a podium for "Applications" papers, theoretical work has been welcomed throughout the 50 year history of the symposium. The theoretical papers referenced in the Appendix however, highlight the growth of numerical methods since the late 1960's. In 1969 Strait and Adams presented some of the early wire antenna theory developed at Syracuse University during and since the famous 1967 paper by Harrington. These methods were used in presentations by many authors during the 1070's and 1980's, but in the late 1980's and throughout the '90's there were a number of publications based on new classes and numerical methods, from finite element to finite difference time domain methods now viable because of the speed and storage of modern PCs, work stations and supercomputers. In '96 Professor Chew of the University of Illinois presented a special session on a variety of these powerful methods.

Mutual coupling phenomena have been described in many Allerton papers over the years, but in a recent coincidence in 1999, a paper by Hansen and one by Chio and Schaubert both revealed the dominant edge effects in the closely spaced

arrays used in wideband systems. This phenomenon may present an ultimate limitation to possible sidelobe control in modest size wideband systems.

Conclusion

The Antenna Applications Symposium and its predecessor the Air Force Antenna Symposium has been an important venue for the presentation of array research and development papers. Allerton papers have most often emphasized the practical engineering aspects of the technology, but ground breaking theoretical work has been presented too. The symposium has become important for the early publication of papers that have later received professional society "Best Paper" awards or have been shown to be the seedlings of new technologies that have gone on to advance phased array technology in major ways.

From the phased array perspective, the symposium has done its job well, and continues to play an important role in the development of phased array technology.